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Research and Development Report

Calibration of Impulse Technique Experimental Set-Up for Determination of Damping Loss Factor

by

Roger M. Crane

DTRC-SME-89/12 Calibration of Impulse Technique Experimental Set-Up for Determination of Damping Loss Factor

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Composite materials are currently being considered for numerous Naval applications. Among their many advantages, their inherent vibration damping characteristics is becoming a dominant design consideration. To date, however, there are no analytical techniques which have the capability of predicting the damping loss factor of a particular composite system. One is therefore limited to experimental determination of the damping loss factor for composite materials which requires a high degree of accuracy and precision. An experimental apparatus has been designed, fabricated and tested using 2024 T-4 aluminum as a calibration material. This material has been well characterized in regard to its damping loss factor. Of critical importance is the material placed between the clamping block and the specimen. These materials act to distribute the load and to minimize frictional losses. Various materials were investigated. The material that provided results which were the most

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ABBREVIATIONS

A/D - analog to digital
dB - decibels
DMA - direct memory access
FFT - Fast Fourier Transform
GPa - Giga Pascals
Hz - Hertz
in - inch
J - Joules
^{o}K - degrees Kelvin
kg - kilograms
m - meters
MHz - Mega hertz
sec - seconds

Abstract

Composite materials are currently being considered for numerous Naval applications. Among their many advantages, their inherent vibration damping characteristics is becoming a dominant design consideration. To date, however, there are no analytical techniques which have the capability of predicting the damping loss factor of a particular composite system. One is therefore limited to experimental determination of the damping loss factor for composite materials which requires a high degree of accuracy and precision. An experimental apparatus has been designed, fabricated and tested using 2024 T-4 aluminum as a calibration material. This material has been well characterized in regard to its damping loss factor. Of critical importance is the material placed between the clamping block and the specimen. These materials act to distribute the load and to minimize frictional losses. Various materials were investigated. The material that provided results which were the most consistent and matched those analytically anticipated was a fiberglass woven supported teflon sheet. Experimental results for the 2024 T-4 aluminum calibration material match those determined analytically to within 5% over a frequency range of 40 to 300 Hz. The variation in results at a particular frequency are within 10%.

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INTRODUCTION

There have been numerous investigators who have developed test techniques for the determination of the damping loss factor for composites. (1-5) For the experimental determination of the damping loss factor of composites, the most recently utilized techniques are the forced resonant vibration technique(1,2) and the impulse technique.(3,4,5) Of these techniques, the impulse technique appears to be the most widely used. In the impulse technique, the specimen is normally held in a cantilever beam configuration, and is excited via an impact near the clamped end. The beam response is measured using either accelerometers or a noncontact eddy current probe. From the beam displacement versus time information, the frequency response function is determined. Using the half power band width method, the loss factor is then calculated.

The manner in which the sample is supported is of vital importance to the accurate determination of the material damping loss factor. Fixturing and materials that are utilized should dissipate a minimal amount of energy. Loss that can occur at the clamping area include frictional losses and dissipation by the material used to clamp the specimen.

There are numerous technical reasons why the impulse technique has gained wide acceptance for testing composites. First, all vibrational frequencies are excited when the specimen is subjected to an impact. Numerous fundamental frequencies and the various modes of vibration can therefore be investigated using a single specimen. This is accomplished by varying the beam length. Secondly, to minimize external energy losses from such sources as friction at the clamped region or from aerodynamic damping, beam tip displacements must be minimized. For low frequencies, which are of major concern for various structural applications, placing the beam into resonant forced vibration results in large tip displacements. The damping loss factor that is therefore determined is a combination of the material internal damping and external losses. This information would therefore be of little use for design purposes. With an impact excitation, minimal force levels can still be used with resultant tip displacements being kept to a minimum.

This paper describes the experimental apparatus developed for the experimental determination of the damping loss factor for composite materials, including both the fixturing and the hardware and software used for data acquisition. In addition, the results of the experimental calibration of this system is reported, where 2024 T-4 aluminum beams are used as the calibration specimen. This material system was chosen since it has been experimentally well characterized and has been shown to analytically follow Zener thermoelastic theory(6) for the damping loss factor as a function of frequency. (7,8)

The experimentally determined damping loss factor results are then compared with the analytically determined loss factor using Zener thermoelastic theory.

EXPERIMENTAL APPARATUS

For vibration damping testing, there are two primary considerations when designing fixturing for testing materials. First, it is necessary that the specimen be isolated from its surroundings. No vibrational energy from external sources should be allowed to influence the vibrational response of the specimen being tested. Accomplishment of this likewise infers that the vibrational energy imparted to the specimen will not be dissipated by the fixturing due to an energy transfer from the specimen. Secondly, care must be taken to minimize all other possible sources of energy dissipation so that the measured damping is the material inherent damping loss factor. Two prevalent sources for external energy dissipation which should be minimized are frictional losses at the clamping regions(2) and aerodynamic damping.(7,9-11)

In order to isolate the specimen from the surroundings, the specimen fixturing was attached to the load frame of a Sontag fatigue test machine, model SF-1U. This machine consists of a 36 x 36 x 3 in. solid steel top attachment plate to which is attached the components for fatigue testing. The entire system is isolated from the machine frame via four springs. The entire system, therefore is isolated from the surroundings. In addition, the mass of this support system is several hundred pounds, which will be not be easily excited by the vibration of the test specimens.

The fixturing that is used for the testing is shown in figure 1. This consists of a steel base plate, 12 x 15 x 1 in., which is bolted to the top plate of the Sontag machine with four 0.75 in. diameter bolts. A solid aluminum breadboard is then bolted to this plate with four screws. The breadboard consists of a 12 x 12 inch plate with 1/4-20 mounting holes on a 1 inch spaced square pattern starting 1.5 inches from the edge. A 4 x 3 x 1.25 in. clamping block base is then attached to the breadboard with three screws. This clamping block base was machined to accept two 0.75 in. diameter tool steel guide posts. These are used to ensure that the specimen will be clamped flat. On top of the clamping block base is positioned the clamping block. This consists of a 4 x 1.25 x 1.25 in. steel plate which is machined to accept linear bearings through which the guide posts will pass. Test specimens with widths up to 1.5 in. and of any thickness can be clamped by this fixture using two 1/4-20 screws.

The eddy current probe is positioned in proximity to the beam tip using the X-Z vernier. The vernier is attached to the breadboard with four cap screws. This specific vernier has a 0.5 inch travel in each direction. By repositioning the vernier at different bolt locations on the breadboard, beams of any length can be interrogated with the eddy current probe. It should be noted that a Plexiglas fixture, to which the eddy current probe is bolted, was fabricated to attach the eddy current probe to the vernier. The use of Plexiglas was required since the eddy current probe was unshielded and metallic structures near the sensor can result in spurious displacement determination. A schematic of the entire assembly is given in figure 2.

EXPERIMENTAL PROCEDURE

For damping loss factor determination, beam tip displacement versus time information is required. The eddy current probe is used to measure the tip displacement. This probe is electrically excited and outputs a voltage dependent on its distance from a conducting medium. This particular probe can be used for both magnetic and non-magnetic materials. The probe has a measuring range of 0.120 inches with a resolution of 0.01% of the measuring range. The probe must first be calibrated before use. To accomplish this, it is placed into a micrometer calibration fixture, Kaman part number 850854-001. Following the calibration procedure, the output of the eddy current probe is adjusted to the requirements of the test. The gain can be adjusted to optimize sensitivity for particular tests. For this test, the probe was calibrated so that 1 volt was equal to 0.040 in. of displacement. Displacement vs. voltage information was obtained using the fixture in increments of 0.005 in. A linear fit was performed on the data and the slope obtained for use in the data reduction programs.

To conduct a test, a specimen is first placed into the test fixture. The eddy current probe is positioned so that its center in approximately 1 in. from the specimen end and in the middle of the specimen width.

The output from the eddy current probe and the force hammer are attached to the MetraByte DAS-16 screw terminal accessory board using BNC connectors. The accessory board is connected to the DAS-16 data acquisition board installed in an IBM PC-AT. This is a 16 channel high speed A/D interface with direct memory access (DMA). This system has a 10 MHz on-board crystal controlled oscillator to provide the time base. The system can be set up to read $\pm$ 5 volts. The information is stored and read in bits with a range of -2048 to 2047 bits corresponding to -5 and +5 volts, respectively. The system resolution, then, with the eddy current probe calibration set to 0.04 in. per volt, is 9.78×10^{-5} in.

A computer program was written in basic which controls the DAS-16 data acquisition. The program utilizes numerous call routines which are provided with the DAS-16 board. The program initially lets the user adjust the height of the probe so that the output of the probe is zero. The program then prompts the user for the appropriate attachments and acquisition rate. The ability to vary the acquisition rate allows the user to zoom into a particular frequency range. In order to prevent aliasing, or distortion of the Fourier transform(12), however, the acquisition rate should be at least 8 times the frequency of interest.

The data acquisition system takes the desired number of data points at the prescribed rate which can be varied up to a maximum of 76 kHz. The data that is taken is stored in a specific memory location which can be accessed to perform a screen plot of the log of the displacement versus time and/or displacement versus time. In the former case, the plot allows the user to make a quick check on the amplitude decay to ensure qualitatively that there are no secondary sources of energy dissipation. This would be indicated by the appearance of two distinct slopes of the peak height values from the log displacement versus time plot. Figure 4 is an example of the log displacement versus time plot from the vibration response of 2024 T-4 aluminum subjected to an impact excitation. Figure 5 is the displacement versus time plot of the same data sample.

The user can likewise continue through the computer routine without plotting the data. At this point, the program prompts the user for the file name and address where the data will be transferred. The data can be transferred as the digital stored information, or it can be stored as actual displacements. An option in the program allows the user to input the specific scaling factors obtained from the calibration of the eddy current probe. The program then creates and opens the storage file and transfers the appropriate data there. In addition, the program places a header in the data file that includes the acquisition rate and interval between data points. A annotated copy of this data acquisition program is given in Appendix 1.

To perform the Fast Fourier Transform (FFT) on the data, the Interactive Laboratory System from Signal Technologies Incorporated is utilized. The system is first used to import the data as a sample file. The system partitions this data into records of up to 1024 data points. The system can then be used to perform the FFT on any record and the information is stored to a file. The system is then used to transfer the FFT information to an ASCII file. The information that is transferred includes the frequency, dB magnitude and phase for each data point.

This file is then read into a word processing software called Wordstar. The frequency, dB magnitude and phase values near the resonant frequency value are read into two files. One file contains approximately twenty data points in which the frequencies are less than the resonant frequency, and the second file contains the twenty data points which are greater than the resonant frequency. The values for each of the two data sets can be easily distinguished from the phase information. In FFT analysis, there is a 2π phase shift at the frequency which corresponds to a resonant frequency. A sample of this phase shift is given in figure 6, where the dB magnitude versus frequency and phase angle versus frequency are given.

The two data sets are then used as input to a basic program. The program converts the dB magnitude information to log values. These converted files are then read into a graphics routine by Golden Software, Inc. called Grapher. Each data set is fit with a fourth order polynomial using orthogonal coefficients. The orthogonal coefficients for the data set given in figure 6 are shown in table 1.

The specific fourth order equation with orthogonal coefficients that is used for the curve fit routine is given as follows

$$\begin{aligned} y = {} & B_1 + (x-\alpha_2)[B_2 + (x-\alpha_3)\{B_3 + (x-\alpha_4)(B_4 + (x-\alpha_5)B_5) - \beta_4 B_5\} - \\ & \beta_3(B_4 + [x - \alpha_5]B_5)] - \beta_2 [B_3 + (x - \alpha_4)(B_4 + (x - \alpha_5)B_5) - \beta_4 B_5] \end{aligned} \quad (1)$$

where the B_i are the orthogonal coefficients, and the α_i and β_i are the recursion factors. The value of x given in equation 1 is calculated from the users x value of the frequencies using the following equation

$$x = \left(\begin{matrix} x \text{ input} \\ [\text{i.e. frequency}] \end{matrix} - x_{mid} \right) x_{scal} \quad (2)$$

where the x_{mid} and x_{scal} are scaling factors for the original frequency data.

A file is then created with the values of the orthogonal factors, and the alpha and beta recursion factors. This file is then used as input to a basic program which calculated the intersection of the two curves, i.e. the left and right curves for the resonant frequency peak, and the frequencies corresponding to the half power points for the specific curves. The half power points are the values of the frequency that correspond to .707 of the magnitude of the peak height value for the resonant peak. The loss factor is then determined using the following equation

$$\eta = \frac{\Delta f_n}{f_r} \tag{3}$$

A copy of the computer program which calculates the loss factor using the fourth order polynomial fit with orthogonal coefficients is given in Appendix 2.

EXPERIMENTAL RESULTS

In order to calibrate the system and to determine the accuracy and precision of the procedure, 2024 T-4 aluminum was tested. Beams were machined from 0.125 in. plate to specimens with widths of 1.0 inches and lengths of 12 inches. The 12 inch lengths were machined parallel to within 0.001 in. to minimize any errors in the test results.

Beam lengths were determined that would result in various first resonant frequencies using the following equation(9)

$$f_i = \sqrt{\frac{EIg}{W_i L^4}} \times C_i \tag{4}$$

where E is the bending stiffness, I is the moment of inertia of the beam, g is the acceleration due to gravity, W_i is the weight per unit length, L is the beam length and C_i is the constant for the i^{th} mode of vibration.(13)

As was previously mentioned, there are two sources of energy dissipation that must be minimized to ensure that the damping loss factor experimentally determined is of the material internal damping and not from external dissipation sources. To minimize aerodynamic damping, loss factors were only determined for samples where maximum tip displacements were less than ± 0.008 in. This represents a displacement less than 7% of the total beam thickness. This was chosen since it was previously shown that aerodynamic damping could be minimized if tip displacements were kept less than 20% of the specimen thickness.(10,11)

The second source of energy dissipation that can be controlled and should be minimized are the frictional losses at the clamped region of the beam. An investigation was conducted where various materials were placed between the specimen and the clamping block. These materials included tapered aluminum clamping blocks, tapered fiberglass blocks, fiberglass fabric reinforced polyurethane sheet, fiberglass fabric reinforced teflon, and no clamping block. These systems were positioned between the sample to be tested and the clamping blocks. The specimens were tested using the procedure described above. The experimentally determined loss factors were compared to that analytically anticipated from Zener Thermoelastic Theory. The clamping material which resulted in the lowest experimental value of the loss factor for the beam was the fiberglass fabric reinforced teflon sheet. The loss factor determined using this material was also the best match to that analytically anticipated. Since all other clamping materials gave results that were higher than anticipated, it was assumed that they were providing additional source for energy dissipation. The material that was used for the rest of the testing was therefore the fiber glass fabric reinforced teflon sheet.

Beam lengths were varied so that the first resonant frequency was varied from approximately 38 Hz. to 300 Hz. The test procedure given above was followed and the loss factors determined. The results from the testing are given in Table 2.

The results of the test program were compared with the predictions determined using Zener thermoelastic theory.(1,2,4,7) The 2024 T-4 aluminum has been shown to follow predictions for the loss factor given by this theory. The loss factor is given by the following

$$\eta = \frac{\alpha^2 E T}{C} \times \frac{\omega \tau}{(1 + \omega^2 \tau^2)} \qquad (5)$$

where α is the coefficient of thermal expansion, E is the bending stiffness of the beam, T is the absolute temperature, C is the heat capacity, ω is the angular frequency and τ is the relaxation time for the heat flow across a beam of rectangular cross section. The value of τ is determined by

$$\tau = \frac{h^2 C}{\pi^2 K} \qquad (6)$$

where h is the beam thickness and K is the thermal conductivity of the beam material.

For each of the beam lengths used in the testing, the first resonant frequency was analytically determined using equation 4.

These results are compared with those determined experimentally in Table 2. All of the experimental values of the first resonant frequency are within the error for the analytically determined values.

Also given in Table 2 are the experimentally determined loss factors. For comparison purposes, the anticipated loss factor of the specimens using Zener thermoelastic theory are given. Table 3 gives the values used for input to equations 5 and 6 for the determination of the damping loss factor for the aluminum calibration specimen. The experimental loss factors are within 2.5% of those analytically anticipated for frequencies less than 196 Hz. At frequencies greater than 196 Hz., the experimental results were within 10% of those anticipated analytically.

The results from the testing are plotted along with the analytical curve of the loss factor from Zener thermoelastic theory in Figure 7. In this figure, the solid curve is the analytical values of the loss factor. A fourth order curve fit was performed on the experimental data to determine the degree of fit of the testing at frequencies between those at which tests were conducted. A plot of the curve fit, also given in figure 7 shown by the dotted line, shows excellent agreement with the plot of the analytically determined values of the loss factor. As can be seen from the plot, the curve fit for the data matches the results predicted by Zener thermoelastic theory to within 2% in the range for which data was taken.

CONCLUSIONS

The experimental apparatus that was designed for determination of the damping loss factor for materials in the cantilever beam configuration accurately determines the damping loss factor with a high degree of precision. Resonant frequencies determined from curve fitting of the frequency response function are within the error of the analytically determined resonant frequencies. The variation in discrete values of the loss factor at a specific frequency have variations of less than 14% with the exception of the data at 312 Hz. where the spread was 22%. The anticipated trends in loss factor for the 2024 T-4 aluminum are determined to within 2% through appropriate curve fitting of the data compared to Zener thermoelastic theory for frequencies from 38 to 100 Hz, and less than 5% for frequencies between 100 and 312 Hz. Secondary sources of energy dissipation have therefore been minimized.

ACKNOWLEDGMENTS

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Table 1: Fourth order polynomial fit statistics for peak values from the FFT given in figure 6.

LEFT SIDE OF PEAK

Degree	Orthogonal Factors	Recursion Factors Alpha	Recursion Factors Beta
0	-3.6147	0	0
1	1.24339	-0.000321833	1.55585
2	0.458577	0.000065269	1.22238
3	0.161536	-0.000107365	1.1425
4	0.0916427	0.000147984	1.07872

RIGHT SIDE OF PEAK

Degree	Orthogonal Factors	Recursion Factors Alpha	Recursion Factors Beta
0	-3.86925	0	0
1	-1.39188	-0.000219959	1.52375
2	0.496194	-0.000141179	1.20287
3	-0.234782	0.000124755	1.13346
4	0.122776	0.000279605	1.08324

Table 2: Experimentally determined vibration damping loss factor results for 2024 T-4 aluminum tested in cantilever beam configuration.

Calculated Resonant Frequency (Hz)	Experimental Resonant Frequency (Hz)	Experimentally Determined Loss Factor ($\times 10^{-4}$)	Average Loss Factor ($\times 10^{-4}$)	Loss Factor from Zener Thermoelastic Theory ($\times 10^{-4}$)
	38.563082	19.66		
38.85±1.40	38.57834	21.91	22.34	22.21
	38.58244	25.45		
	49.0575	22.12		
	49.0637	21.99		
	49.0639	22.79	22.74	22.94
48.91±1.76	49.0684	20.29		
	49.0706	24.85		
	49.0909	23.02		
	49.5670	22.57		
	77.17365	20.30		
78.29±2.82	77.18895	21.24		
	77.20165	18.52	20.23	20.70
	77.2040	20.85		
	77.25243	20.25		
	80.1034	20.00		
80.38±2.89	80.1891	21.28	20.54	20.04
	80.2092	19.99		
	80.2496	20.88		
96.82±3.49	95.328	18.44	18.52	18.62
	96.47	18.60		
195.20±7.03	197.2326	11.85		
	197.2516	11.35	11.09	10.90
	197.1784	10.08		
	198.1793	9.84		
199.73±7.19	198.2263	8.62	9.59	10.64
	198.5398	10.31		
	219.628	8.28		
223.92±8.06	219.645	8.59	9.08	9.61
	219.856	9.35		
	220.041	10.09		
	305.1664	8.00		
312.08±11.24	305.1771	7.69	7.58	7.05
	305.1800	5.83		
	305.1902	8.80		

Table 3: Input values used in equations 3 and 4 for the determination of the damping loss factor for the aluminum calibration specimen using Zener thermoelastic theory.

INPUT PARMETER	COEFFICIENT OF THERMAL EXPANSION	BENDING STIFFNESS	TEMPERATURE (ABSOLUTE)	HEAT CAPACITY	THERMAL CONDUCTIVITY
SYMBOL	α	E	T	C	K
VALUE	23.2×10^{-6} $\left(\frac{in/in}{^{\circ}K}\right)$	73.097 GPa	298.72 ($^{\circ}$K)	2560511.2 $\left(\frac{J}{m^{3}\ ^{\circ}K}\right)$	126.47 $\left(\frac{kg\ m}{sec^{3}\ ^{\circ}K}\right)$

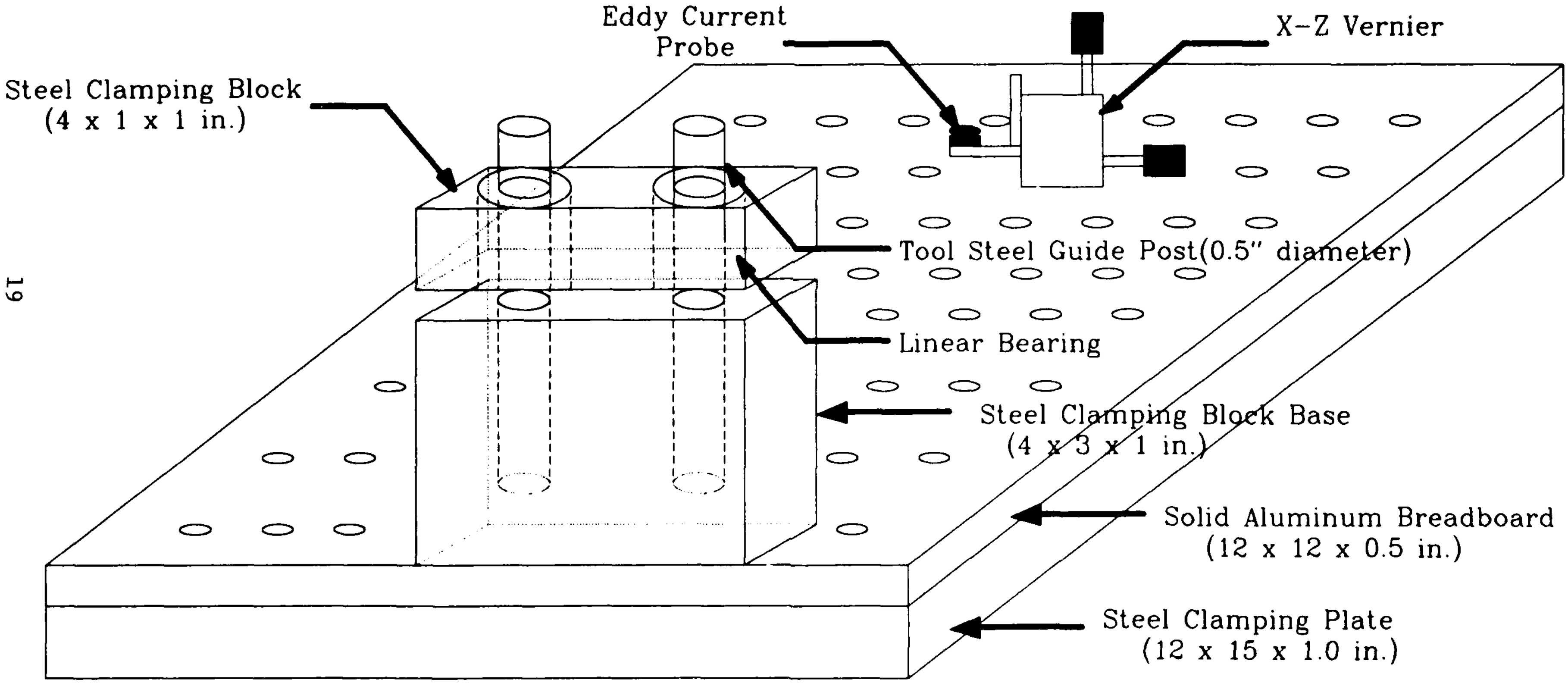

Figure 1: Schematic diagram of experimental apparatus for vibration damping testing.

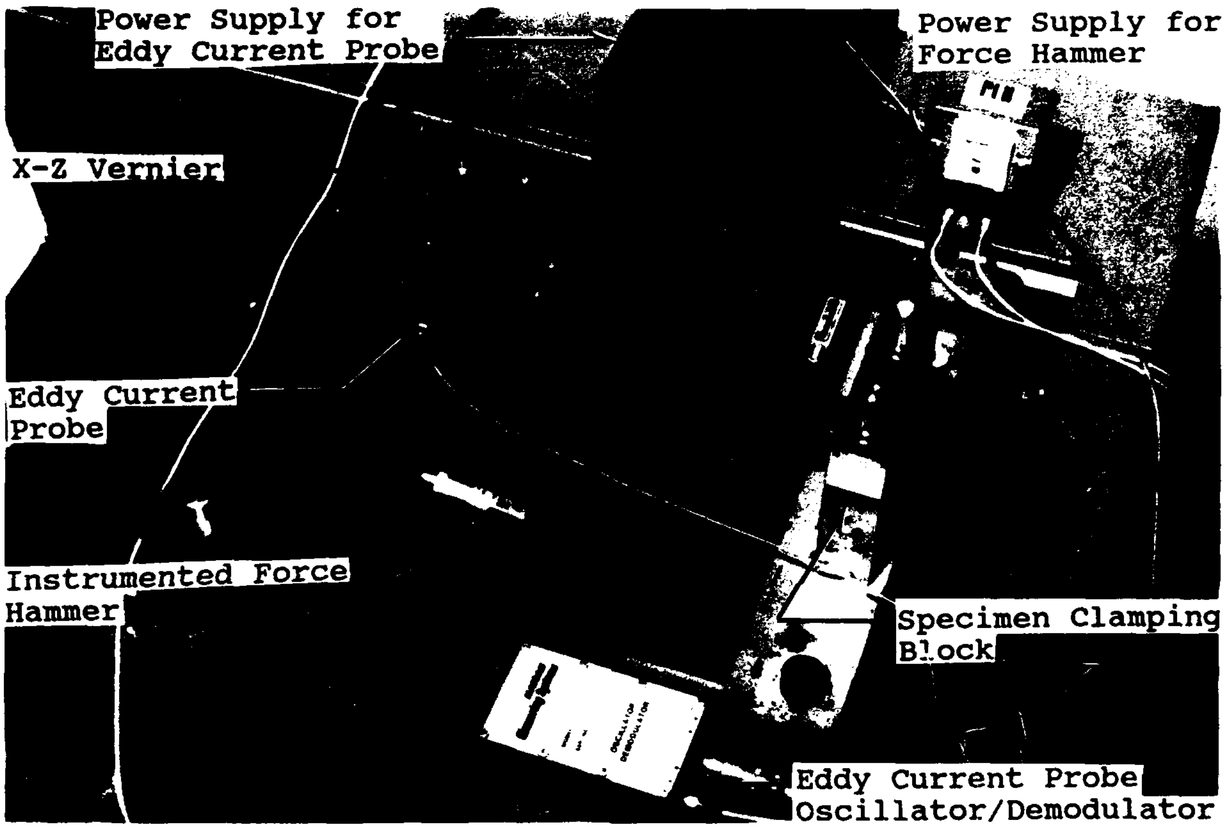

Figure 2: Experimental apparatus used for the vibration damping testing with 2024 T-4 Aluminum specimen.

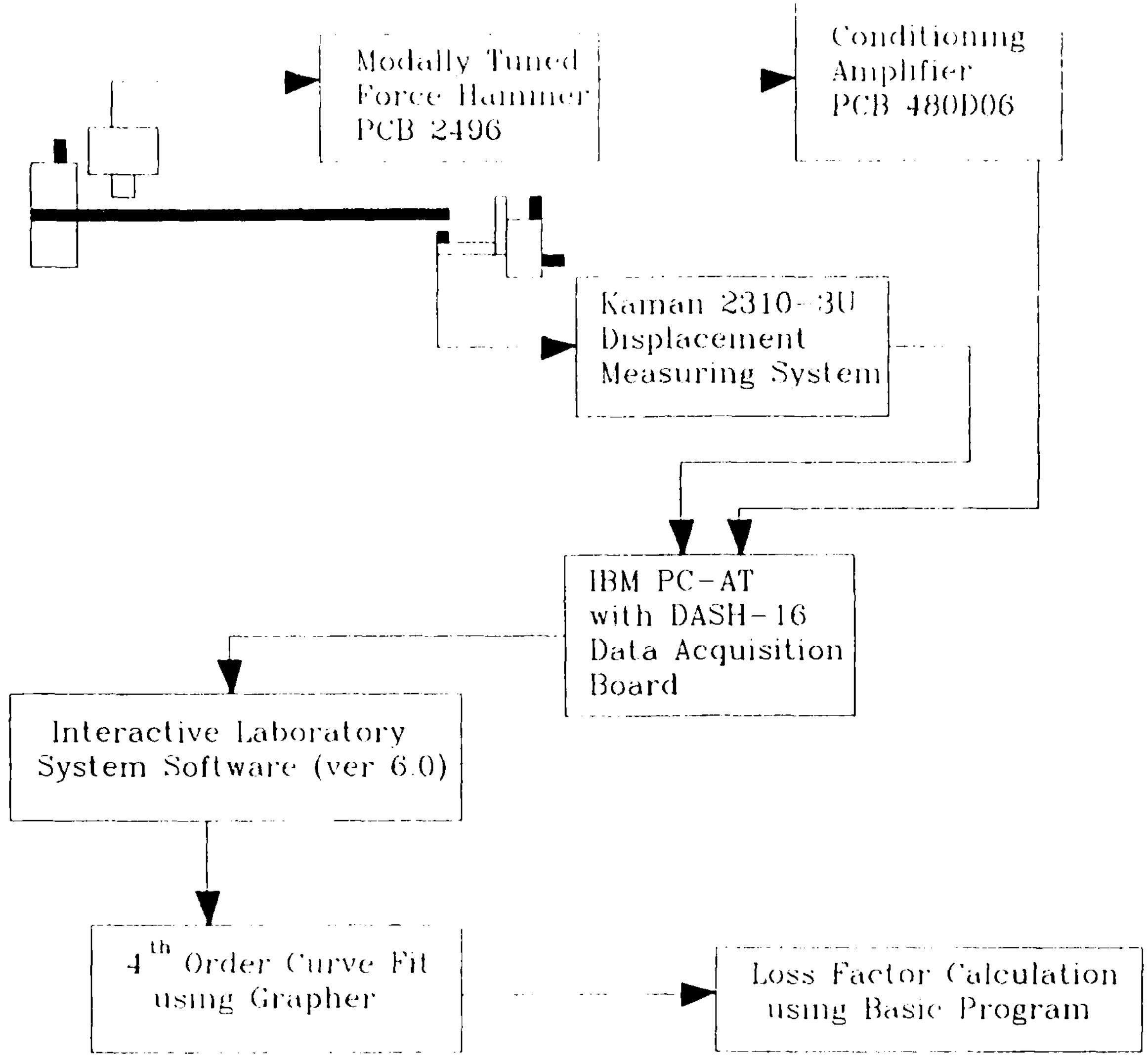

Figure 3: Schematic of vibration damping test equipment

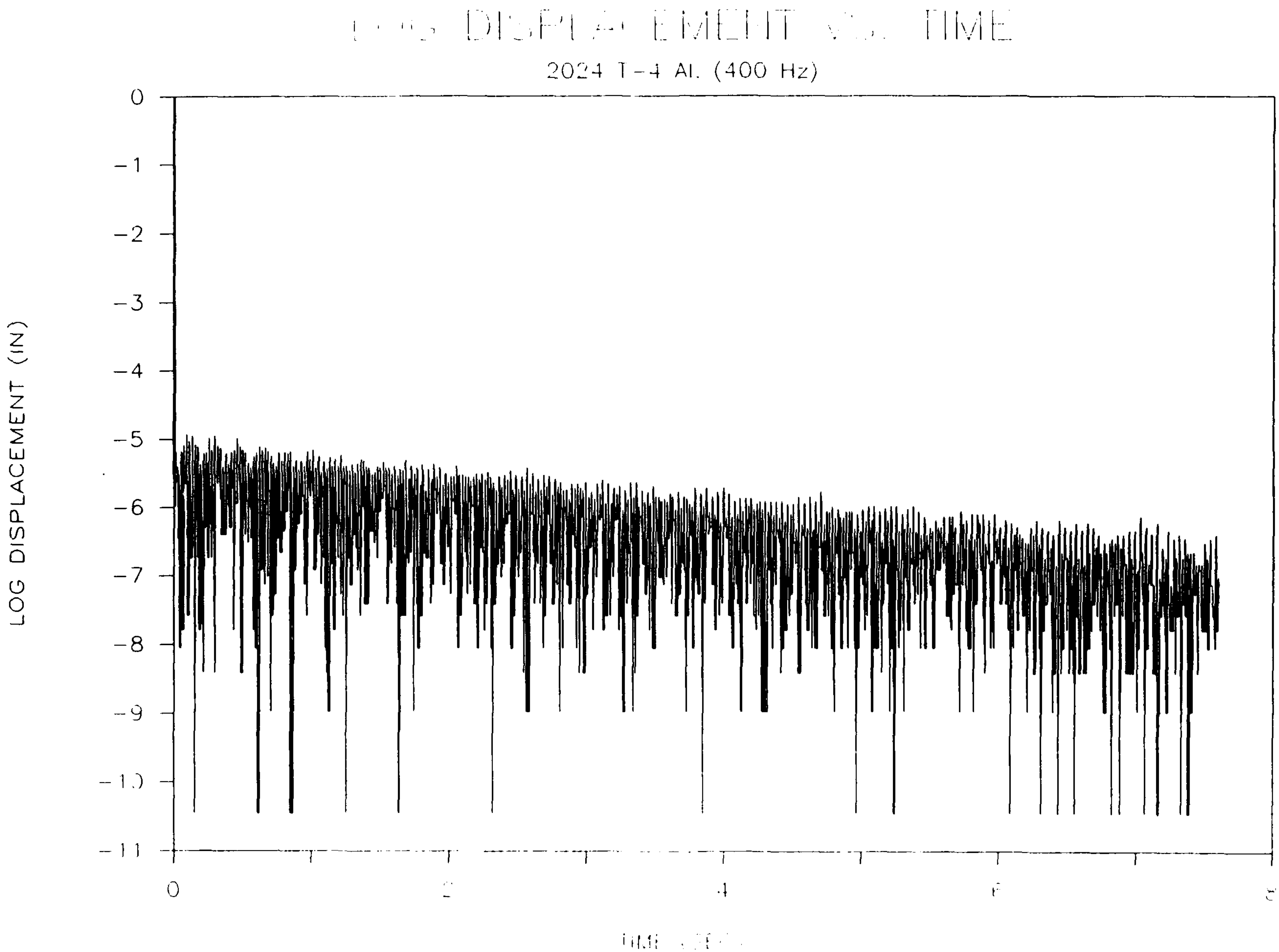

Figure 4: Log displacement versus time information for 2024 T-4 *Aluminum sample data*

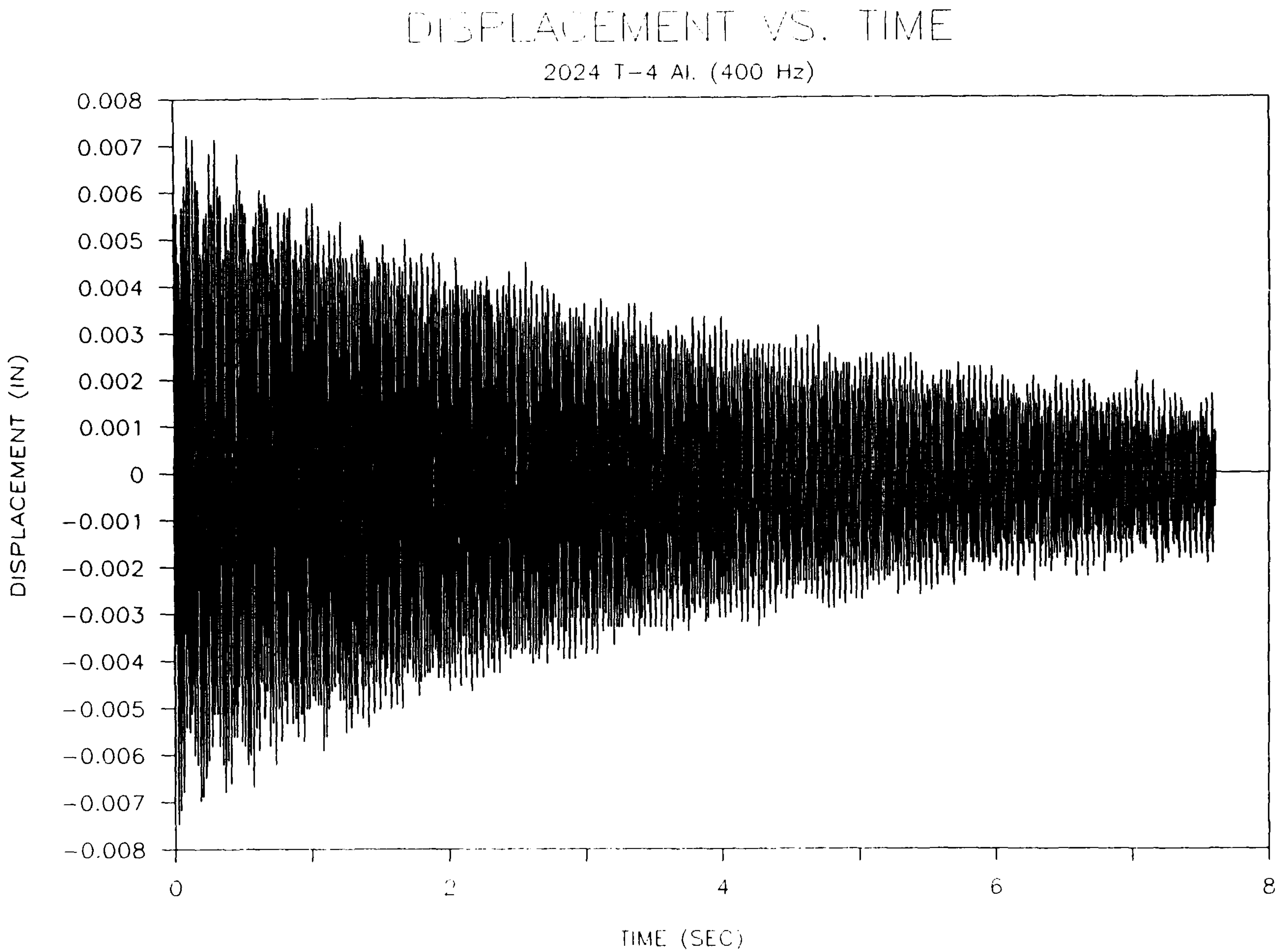

Figure 5: Displacement versus time information for 2024 T-4 Aluminum sample data.

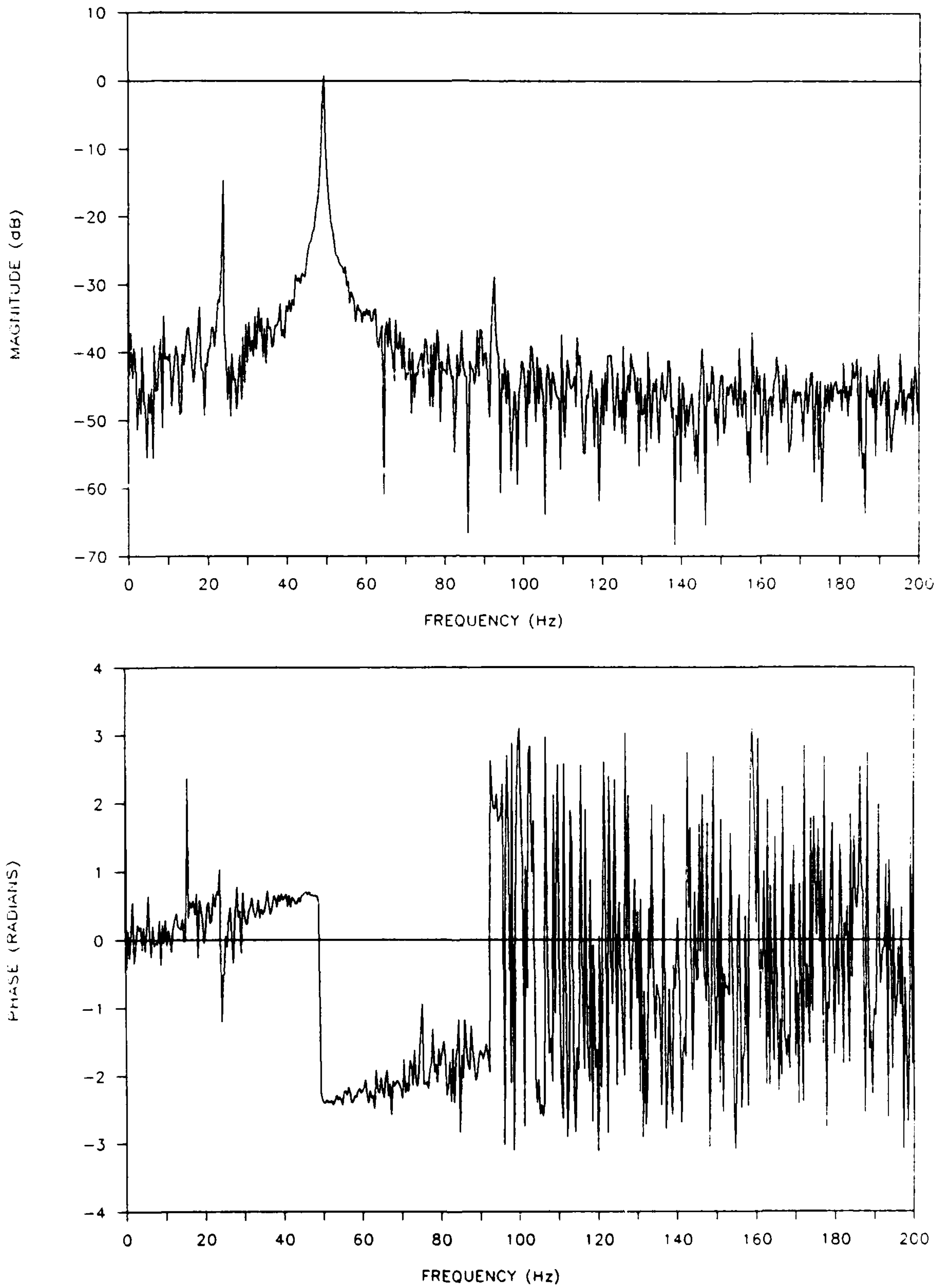

Figure 6: FFT of 2024 T-4 Aluminum showing dB magnitude versus frequency and phase angle versus frequency.

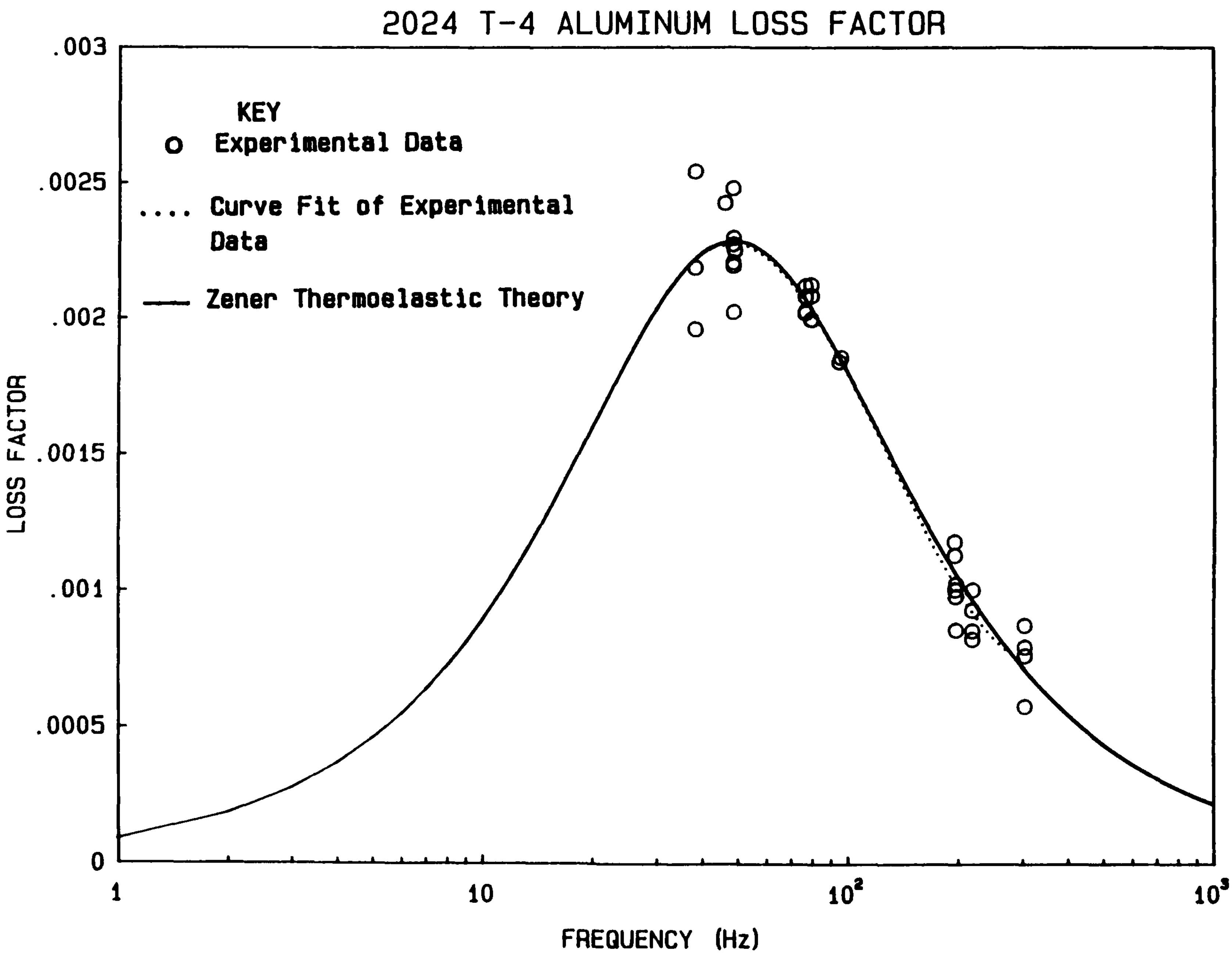

Figure 7: Loss factor for 2024 T-4 Aluminum determined using Zener Thermoelastic Theory and from experimental testing.

REFERENCES

1. Gibson R.F. and Plunkett, R., "A Forced-vibration Technique for Measurement of Material Damping ", Experimental Mechanics, vol.11, no.8, August 1977, pp. 297-302

2. Gibson, R.F., Yau, A., and Riegner, D.A., "An Improved Forced-vibration Technique for Measurement of Material Damping", Experimental Techniques, vol.6, no.2, April 1982, pp. 10-14

3. Suarez, S.S., Gibson, R.F., and Deobald, L.R., "Random and Impulse Techniques for Measurement of Damping in Composite Materials", Experimental Techniques, vol.8, no.10, Oct. 1984, pp.19-24

4. Sun. C.T., Lee, B.T., and Chaturvedi, S.K., "Composite Material Damping Using Impulse Technique ", Vibration Damping 1984 Workshop Proceedings, Long Beach, CA. 27-29 Feb. 1984, Report No. AFWAL-TR-84-3064, Section P, 24 p.

5. Suarez, S.A., Gibson, R.F., Sun, C.T., and Chaturvedi, S.K., "The Influence of Fiber Length and Fiber Orientation on Damping and Stiffness of Polymer Composite Materials", Experimental Mechanics, vol.26, no.2, June 1986, pp. 175-184

6. Zener, C.M., <u>Elasticity and Anelasticity of Metals</u>, Chicago, University of Chicago, 1948,

7. Granick, N. and Stern, J.E., "Material Damping of Aluminum by a Resonant Dwell Technique ", NASA TN-D-2895, 1965, 24 p.

8. Crandall, S.H., "On Scaling Laws for Material Damping ", NASA-TN-D-1467, 1962, 21 p.

9. Gibson, R.F. and Plunkett, R., "A Forced-Vibration Technique for Measurement of Material Damping," Experimental Mechanics, vol.11, no.8, August 1977, pp. 297-302

10. Gibson, R.F., Yau, A., and Reigner, D.A., "An Improved Forced Vobration Technique for Measurement of MAterial Damping," Experimental Techniques, Vol.6, No.2, April 1982, pp. 10-14

11. Gibson, R.F, Yau, A., and Reigner, D.A., "Vibration Characteristics of Automotive Composite Materials," Short Fiber Reinforced Composites, American Society for Testing and Materials STP 772, Minneapolis, Minn., 14-15 April 1982, pp. 133-150

12.Yang, C.Y., Random Vibration of Structures, John Wiley & Sons, Inc., New York, 1986

13. <u>Marks' Standard Handbook for Mechanical Engineers</u>, ed. by Theodore Baumeister, Eugene A. Avalone, and Theodore Baumeister III, Eighth Edition, McGraw-Hill Book Company, New York, 1978.

APPENDIX 1: An annotated Basic computer routine used for the data acquistion system to read displacement versus time.

```
10 ' THIS PROGRAM IS THE DATA AQUISITION PROGRAM FOR THE VIBRATION DAMPING
20 ' PROJECT. THIS IS SET UP TO READ CHANNEL 0 AS THE DISPLACEMENT SENSOR
30 ' AND CHANNEL 1 AS THE FORCE HAMMER. THE PROGRAM TAKES DATA AT YOUR
40 ' PRESCRIBED RATE AND WRITES IT TO A DATA ARRAY, CH% AND DT. THE PROGRAM
50 ' PLOTS THE ABSOLUTE VALUE OF THE LOG OF THE DISPLACEMENT VS. TIME. THE
60 ' DATA CAN BE SAVED IN EITHER THE DIGITAL VALUE FORM (-2048 TO 2047) OR
70 ' CAN BE SCALED BEFORE BEING SAVED TO A FILE. THE DIGITAL DATA FILE NAME
80 ' WILL BE VIBDATA.DAT WHILE THE SCALED DATA WILL BE VIBDATA.PRN. THE PROGRAM
90 ' WILL ALLOW YOU TO MAKE THE APPROPRIATE SCALING FACTOR CHANGES.
100 ' *******************************************************************
110 ' THIS PROGRAM IS CALLED VIBDAMP.BAS
120 ' *******************************************************************
125 DIM DT%(12000)
126 DIM CH%(12000)
127 KEYPRESSED = 0
128 CLS
130 '
140 '  LOAD DASH16.BIN DRIVER
150 '
160 DEF SEG = &H5000
170 BLOAD "C:\ILS\DAS\DASH16.BIN", 0
180 '
190 ' *** INITIALIZE WITH MODE 0
200 '
210 MD% = 0
220 DIO%(0) = &H330          ' SET I/O ADDRESS
230 DIO%(1) = 2              ' SET INTERRUPT LEVEL
240 DIO%(2) = 3              ' SET DMA LEVEL
250 FLAG% = 0
260 DASH16 = 0
270 CALL DASH16 (MD%, DIO%(0), FLAG%)
280 IF FLAG%<>0 THEN PRINT "INSTALLATION ERROR";STOP
290 '
300 ' ***  SET MULTIPLEXER SCAN LIMITS
310 MD% = 1
320 'INPUT "ENTER LOWER SCAN LIMIT, (0-7) :",LL%
330 'DIO%(0) = LL%
340 'INPUT "ENTER UPPER SCAN LIMIT, (0-7) :", UL%
350 'DIO%(1) = UL%
360 PRINT
370 PRINT " ATTACH THE OUTPUT FROM THE EDDY CURRENT PROBE TO CHANNEL 0"
380 PRINT " AND THE OUTPUT FROM THE FORCE HAMMER TO CHANNEL 1"
390 INPUT " AFTER DOING THIS, HIT ANY KEY ",Z$
395 CLS
400 DIO%(0) = 0
410 DIO%(1) = 0
420 CALL DASH16 (MD%, DIO%(0), FLAG%)
430 IF FLAG%<>0 THEN PRINT "ERROR # ";FLAG%;"IN SETTING SCAN LIMITS":STOP
440 '
450 '  *** DO ONE A/D CONVERSION AND INCREMENT MUX
460 '
470 PRINT
480 'MD% = 3
490 'CALL DASH16 (MD%, DIO%(0), FLAG%)
500 'PRINT USING "CHANNEL ##  READS  ##### BITS";DIO%(1), DIO%(0)
510 'INPUT "DO YOU WANT TO DO ANOTHER ?", A$
520 'IF A$ = "Y" OR A$ = "y" THEN 410
530 '  *** DO 1266 A/D CONVERSIONS AND PRINT AVERAGE
540 PRINT
550 PRINT " THE FOLLOWING SECTIONS WILL ALLOW YOU TO ADJUST ZERO FOR THE"
```

```
560 PRINT " EDDY CURRENT PROBE. ADJUST THE VERNIER FOR THE PROBE HOLDER"
570 PRINT " UNTIL THE OUTPUT IS CLOSE TO 0. THEN HIT ANY KEY TO CONTINUE"
580 WHILE NOT KEYPRESSED
590  MD% = 17
600 DIO%(0) = 10 ' DIVIDE 10 MHz BY 10 TO GIVE 1MHz FREQUENCY
610 DIO%(1) = 13 ' DIVIDE 1 MHz BY 12 TO GIVE 83.3 KHz FREQUENCY
620 FLAG% = 0
630 CALL DASH16 (MD%, DIO%(0), FLAG%)
640 DIO%(0) = 1266
650 DIO%(1) = &H6800   ' SEGMENT OF MEMORY TO RECIEVE DATA
660 DIO%(2) = 1   'INDICATES TYPE OF TRIGGER; 1 = TIMER, 0 = EXTERNAL TRIGGER
670 DIO%(3) = 0   ' 0 = ONE CYCLE,  1 = RECYCLE
680 MD% = 6
690 CALL DASH16 (MD%, DIO%(0), FLAG%)
700 MD% = 8
710 CALL DASH16 (MD%, DIO%(0), FLAG%)
720 IF DIO%(1) = 1 THEN GOTO 700
730 MD% = 9
740 DIO%(0) = 1266               ' NUMBER OF WORDS TO TRANSFER
750 DIO%(1) = &H6800             ' SEGMENT OF MEMORY TO TRANSFER FROM
760 DIO%(2) = 0                  ' SET TRANSFER TO BEGIN AT BEGINNING OF SEGMENT
770 DIO%(3) = VARPTR(DT%(0))     ' TO START TRANSFER AT BEGINNING OF ARRAY
780 DIO%(4) = VARPTR(CH%(0))     ' CHANNEL THAT DATA IS FROM
785 CALL DASH16 (MD%, DIO%(0), FLAG%)
790 IF KEYPRESSED$<>"" THEN KEYPRESSED=-1
800 SUM = 0
810 FOR I = 1 TO 1266
820 SUM = SUM +DT%(I)
830 NEXT I
840 ZERO= SUM/1266
850 LOCATE 15,20
860 PRINT USING "###.###";ZERO
870 KEYPRESSED$=""
880 KEYPRESSED$=INKEY$
890 WEND
895 '
896 ' ***  SET MULTIPLEXER SCAN LIMITS
897 MD% = 1
898 DIO%(0) = 0
899 DIO%(1) = 1
900 CALL DASH16 (MD%, DIO%(0), FLAG%)
901 IF FLAG%<>0 THEN PRINT "ERROR # ";FLAG%;"IN SETTING SCAN LIMITS":STOP
909 '
910 ' *** SET PROGRAMMABLE TIMER RATE USING MODE 17
920 '     SO THAT TIMER CAN BE SET TO MAX. VALUE
930 ' NOTE THAT CURRENT TIME FOR 2 CHANNEL SCAN IS 1.30 E-5 SEC."
940 '
950 PRINT "DO YOU WANT TO CHANGE THE VALUES FOR THE PROGRAMMABLE TIMER"
960 PRINT " THE CURRENT SETTING IS FOR A FREQUENCY OF 76.9 KHz. THIS IS"
970 PRINT " THE MAXIMUM FREQUENCY. ANY NEW FREQUENCY WILL BE LOWER THAN"
980 INPUT " THIS. DO YOU WANT TO CHANGE FREQUENCIES ";A$
990 PRINT
1000 IF A$ = "N" OR A$ = "n" THEN GOTO 1140
1010 PRINT " TO SET A NEW FREQUENCY, INPUT TWO NUMBERS WHICH WILL"
1020 PRINT " BE DIVIDED INTO 10 MHz THAT WILL RESULT IN THE FREQUENCY"
1030 INPUT " THAT YOU DESIRE; A,B (CURRENT DIVISOR IS 130) ";D,V
1040 K = D*V
1050 PRINT
1060 TI#= 1E+07/K
1070 IF K>=130 GOTO 1170
```

```
1080 PRINT
1090 PRINT " YOU MUST CHOOSE A DIVIDE BY GREATER THAN 130 IN ORDER TO"
1100 PRINT " COLLECT DATA CORRECTLY. PLEASE INPUT VALUES WHICH HAVE A"
1110 PRINT " PRODUCT GREATER THAN 130 !!! "
1120 PRINT
1130 GOTO 1010
1140 D=5
1150 V = 26
1160 TI#= 1E+07/130
1170  MD% = 17
1180 DIO%(0) = D  ' DIVIDE 10 MHz BY 10 TO GIVE 1MHz FREQUENCY
1190 DIO%(1) = V  ' DIVIDE 1 MHz BY 12 TO GIVE 83.3 KHz FREQUENCY
1200 FLAG% = 0
1210 CALL DASH16 (MD%, DIO%(0), FLAG%)
1220 '
1230 ' *** DO N A/D CONVERSIONS AND TRANSFER TO MEMORY VIA DMA - MODE 6
1240 '
1250 INPUT "ENTER NUMBER OF CONVERSIONS DESIRED (UP TO 12000): ",M
1270 PRINT
1280 PRINT "THE SYSTEM WILL BEGIN TAKING DATA FROM ASSIGNED CHANNELS"
1290 INPUT "WHEN READY, STRIKE ANY KEY AND DATA COLLECTION WILL BEGIN ",A$
1300 DIO%(0) = M
1310 DIO%(1) = &H6800   ' SEGMENT OF MEMORY TO RECIEVE DATA
1320 DIO%(2) = 1   'INDICATES TYPE OF TRIGGER; 1 = TIMER, 0 = EXTERNAL TRIGGER
1330 DIO%(3) = 0   ' 0 = ONE CYCLE,  1 = RECYCLE
1340 MD% = 6
1350 CALL DASH16 (MD%, DIO%(0), FLAG%)
1360 MD% = 8
1370 CALL DASH16 (MD%, DIO%(0), FLAG%)
1380 IF DIO%(1) = 1 THEN GOTO 1360
1390 '
1400 PRINT CHR$(7)
1410 '
1420 '*** TRANSFER DATA FROM MEMORY TO ARRAY USING MODE 9
1430 MD% = 9
1440 DIO%(0) = M                ' NUMBER OF WORDS TO TRANSFER
1450 DIO%(1) = &H6800           ' SEGMENT OF MEMORY TO TRANSFER FROM
1460 DIO%(2) = 0                ' SET TRANSFER TO BEGIN AT BEGINNING OF SEGMENT
1470 DIO%(3) = VARPTR(DT%(0))   ' TO START TRANSFER AT BEGINNING OF ARRAY
1480 DIO%(4) = VARPTR(CH%(0))   ' CHANNEL THAT DATA IS FROM
1490 CALL DASH16 (MD%, DIO%(0), FLAG%)
1500 PRINT CHR$(2)
1510 '
1520 ' READ DATA FROM MEMORY SEGMENT AND PRINT GRAPHICS, LOG(DISPLACEMENT)
1530 ' VS. TIME AND FORCE VS. TIME
1540 '
1550 FOR I = 1 TO M-1 STEP 2          ' SEARCH HAMMER ARRAY FOR WHEN VALUE
1560 IF DT%(I) < 250 THEN GOTO 1600   ' REACHES A PRESET VOLTAGE INDICATING
1570 B = I - 21                       ' HAMMER IMPACT. STORE ARRAY NUMBER AS B
1580 K = (M-B)/640              ' K SCALES TIME TO FIT ON X-AXIS
1590 GOTO 1620
1600 NEXT I
1610 B = M-21
1620 Q=0
1630 FOR I = 0 TO M STEP 2           ' SEARCH FOR MAXIMUM VALUE OF DISPLACEMENT
1640 IF ABS(DT%(I)) < Q THEN GOTO 1660    ' SO THAT GRAPHICS CAN BE SCALED
1650 Q = DT%(I)
1660 NEXT I
1670 R#=Q/50
1680 INPUT "DO YOU WANT TO PLOT LOG(DISPLACEMENT) VS. TIME ";A$
```

```
1690 IF A$ = "N" OR A$ = "n" THEN GOTO 1820
1700 CLS:SCREEN 2:KEY OFF
1710 W = (LOG(Q))/100              ' W SCALES DISPLACEMENT TO FIT ON Y-AXIS
1720 FOR I = B TO M-1 STEP 2       ' LINES 1230 - 1410 PLOTS DISPLACEMENT
1730 Z = ABS(DT%(I))               ' AND FORCE VS. TIME USING LOG PLOT
1740 IF Z = 0 THEN GOTO 1780
1750 L = LOG(Z)
1760 PSET ((I-B)/K, (100 - (L/W)))
1770 GOTO 1790
1780 PSET ((I-B)/K, 100)
1790 PSET ((I-B)/K, (190-(DT%(I+1)/23)))
1800 NEXT I
1810 INPUT "",A$
1820 INPUT "DO YOU WANT TO PLOT THE SAME DATA USING DISPLACEMENT VS. TIME";A$
1830 IF A$ = "N" OR A$ = "n" THEN GOTO 1920
1840 CLS:SCREEN 2:KEY OFF
1850 FOR I = B TO M-1 STEP 2
1860 PSET ((I-B)/K, (51-(DT%(I)/R#)))
1870 PSET ((I-B)/K, 51)
1880 PSET ((I-B)/K, (195-(DT%(I+1)/23)))
1890 NEXT I
1900 N = M-B
1910 INPUT "",A$
1920 PRINT "NUMBER OF DATA POINTS IS ";N
1930 INPUT "WOULD YOU LIKE TO CHANGE THE START OF THE DATA ";A$
1940 IF A$ = "N" OR A$ = "n" THEN GOTO 1970
1950 PRINT "THE CURRENT VALUE OF THE START FOR DATA IS ";B
1960 INPUT " ENTER NEW VALUE FOR START OF DATA TRANSFER ";B
1970 CLS:SCREEN 0
1980 '
1990 '*** TRANSFER DATA
2000 '
2010 PRINT " THE DATA WILL NOW BE PRINTED TO A FILE. INSERT A DATA DISK IN"
2020 PRINT " DRIVE A. INPUT THE NAME YOU WISH TO CALL THIS FILE"
2030 PRINT " PLEASE USE THE EXTENSION OF 'PRN' FOR YOUR FILE ";
2040 INPUT "",FILE$
2042 B$ = ":"
2044 IF INSTR(FILE$,B$) = 0 THEN GOTO 2047
2045 C$=FILE$
2046 GOTO 2050
2047 A$="A:"
2048 C$=A$+FILE$
2050 PRINT
2060 PRINT " CURRENT ARRAY WILL BE TRANSFERRED TO A FILE, ";C$
2065 PRINT
2070 PRINT " YOU CAN SCALE THE DATA OR PRINT THE DIGITAL DATA TO THIS FILE"
2075 PRINT
2080 PRINT " THE SCALING FACTORS ARE CURRENTLY SET WITH A "
2090 PRINT " SLOPE AND INTERCEPT FOR DISPLACEMENT OF 3.989063E-2 AND "
2100 PRINT "2.897717E-5, RESPECTIVELY. DO YOU WANT TO PRINT THE DIGITAL"
2130 INPUT "DATA TO FILE";A$
2140 IF A$="Y" OR A$="y" THEN GOTO 2340
2145 PRINT
2150 PRINT "DO YOU WANT TO CHANGE THE SLOPE AND INTERCEPT OF THE EDDY"
2160 INPUT "CURRENT PROBE FROM 3.989063E-2 AND 2.897717E-5, RESPECTIVELY";A$
2170 IF A$ = "N" OR A$ = "n" THEN GOTO 2210
2180 PRINT
2190 INPUT " INPUT NEW SLOPE AND INTERCEPT IN FORMAT, S,I ";S#,E#
2200 GOTO 2230
2210 S#= 3.989063E-02
```

```
2220 E#= 2.89771E-05
2230 OPEN C$ FOR OUTPUT AS #1
2240 PRINT #1,"THE FREQUENCY OF TEST IS ";TI#/2
2250 PRINT #1,"THE TIME INTERVAL BETWEEN DATA POINTS IS ";2/TI#
2260 FOR I = B TO M STEP 2
2270 DT# = DT%(I)/409.4
2280 DT# = S# * DT# + E#
2290 PRINT #1,DT#
2300 NEXT I
2310 CLOSE #1
2320 PRINT "THE NUMBER OF CONVERSIONS THAT HAVE BEEN MADE IS ";N
2330 GOTO 2435
2340 PRINT "THE DIGITAL DATA WILL BE STORED IN FILE ";C$
2350 PRINT "THE NUMBER OF DATA POINTS ARE ";M-B
2360 OPEN C$ FOR OUTPUT AS #1
2370 PRINT "THE FREQUENCY OF DATA ACQUSITION IS ";TI#/2
2380 FOR I = B TO M-1 STEP 2
2400 PRINT #1, DT%(I)
2410 'PRINT #1,T#;DT%(I);DT%(I+1)
2420 NEXT I
2430 CLOSE #1
2435 PRINT
2440 PRINT "WOULD YOU LIKE TO RUN THIS PROGRAM AGAIN ? ";
2450 INPUT "",M$
2460 IF M$ = "Y" OR M$ = "y" THEN GOTO 127
2470 END
```

APPENDIX 2: Basic computer routine used for the determination of the resonant frequency and damping loss factor from the fourth order curve fit values using the half power band width method.

```
10 '  ****** THE FOLLOWING PROGRAM IS CALLED 4ORTHOFIT  *****
20 '
30 ' THIS PROGRAM PERFORMS A FIT TO DATA IN A DATA FILE FOR A
40 ' FOURTH ORDER POLYNOMIAL FIT WITH ORTHOGONAL COEFFICIENTS
50 ' THE INFORMATION IS READ FROM A FILE AND YOU ARE PROMPTED FOR
60 ' THE APPROPRIATE INFORMATION
70 '
80 PRINT " IN ORDER TO RUN THIS PROGRAM, YOU NEED TO HAVE A DATA FILE "
90 PRINT " THAT HAS THE FOURTH ORDER POLYNOMIAL COEFFICIENTS ALONG WITH"
100 PRINT " THE ALPHA AND BETA VALUES.  THEY SHOULD BE INPUT FOR EACH"
110 PRINT " EQUATION IN THE FORM: "
120 PRINT " A, B, C, D, E"
130 PRINT " A1, A2, A3, A4, A5 "
140 PRINT " B1, B2, B3, B4, B5"
150 PRINT
160 PRINT " WHERE THE FORM OF THE EQUATION IS EX^4+DX^3+CX^2+BX+A "
170 PRINT " AND A1 - A5 AND B1 - B5 ARE THE ALPHA AND BETA COEFFICIENTS"
180 PRINT " AS DETERMINED USING GRAPHER POLYNOMIAL FIT "
190 PRINT
200 PRINT " INPUT THE NAME OF THE FILE THAT HAS THE COEFFICIENTS FOR THE "
210 PRINT " FOURTH ORDER POLYNOMIAL FIT WITH ORTHOGONAL COEFFICIENTS "
220 PRINT " IN THE FORMAT AS INDICATED ABOVE ";
230 INPUT "",A$
240 OPEN A$ FOR INPUT AS #1
250 INPUT #1,A#,B#,C#,D#,E#
260 INPUT #1,A1#,A2#,A3#,A4#,A5#
270 INPUT #1,B1#,B2#,B3#,B4#,B5#
280 INPUT #1,F#,G#,H#,I#,J#
290 INPUT #1,A11#,A12#,A13#,A14#,A15#
300 INPUT #1,B11#,B12#,B13#,B14#,B15#
310 PRINT
320 CLS
330 PRINT " THE COEFFICIENTS FOR THE FIRST EQUATION FOR THE POLYNOMIAL FIT"
340 PRINT " IN THE FORM EX^4+DX^3+CX^2+BX+A ARE "
350 PRINT E#;"X^4 + ";D#;"X^3 + ";C#;"X^2 + ";B#;"X + ";A#
360 PRINT
370 PRINT " THE VALUES FOR THE ALPHAS IN THE ORTHOGONAL FIT FOR THE FIRST"
380 PRINT " EQUATION ARE ";A1#;A2#;A3#;A4#;A5#
390 PRINT
400 PRINT  " THE VALUES FOR THE BETAS IN THE ORTHOGONAL FIT FOR THE FIRST "
410 PRINT " EQUATION ARE ";B1#;B2#;B3#;B4#;B5#
420 PRINT
430 PRINT " THE COEFFICIENTS FOR THE SECOND EQUATION FOR THE POLYNOMIAL FIT"
440 PRINT " IN THE FORM EX^4+DX^3+CX^2+BX+A ARE "
450 PRINT J#;"X^4 + ";I#;"X^3 + ";H#;"X^2 + ";G#;"X + ";F#
460 PRINT
470 PRINT " THE VALUES FOR THE ALPHAS IN THE ORTHOGONAL FIT FOR THE SECOND"
480 PRINT " EQUATION ARE ";A11#;A12#;A13#;A14#;A15#
490 PRINT
500 PRINT  " THE VALUES FOR THE BETAS IN THE ORTHOGONAL FIT FOR THE SECOND"
510 PRINT " EQUATION ARE ";B11#;B12#;B13#;B14#;B15#
520 PRINT
530 PRINT " INPUT THE LOWER AND UPPER BOUND FOR THE FREQUENCY FOR WHICH"
540 PRINT " PROGRAM WILL SEARCH FOR A SOLUTION ";
550 INPUT "",XL#,XR#
555 XM#=(XL#+XR#)/2
556 FL#=XL#
557 FR#=XR#
560 CLOSE #1
580 XL4#=E#
```

```
590 XL3#=D#-E#*A5#-A4#*E#-A3#*E#-A2#*E#
600 XL2#=E#*A5#*A4#-D#*A4#+C#-B4#*E#-A3#*D#+A3#*A5#*E#+A3#*A4#*E#
610 XL2#=XL2#-E#*B3#-A2#*D#+A2#*A5#*E#+A2#*A4#*E#+A2#*A3#*E#
620 XL2#=XL2#-B2#*E#
630 XL1#=A3#*A4#*D#-A3#*A4#*A5#*E#-A3#*C#+A3#*B4#*E#-B3#*D#+A5#*B3#*E#
640 XL1#=XL1#+B#+A2#*A4#*D#-A2#*A4#*A5#*E#-A2#*C#+A2#*B4#*E#+A2#*A3#*D#
650 XL1#=XL1#-A2#*A3#*A5#*E#-A2#*A3#*A4#*E#+A2#*B3#*E#-B2#*D#
655 XL1#=XL1#+A5#*B2#*E#+A4#*B2#*E#
660 XL0#=A2#*A3#*A4#*A5#*E#-A2#*A3#*A4#*D#+A2#*A3#*C#
670 XL0#=XL0#-A2#*A3#*B4#*E#+A2#*B3#*D#-A2#*A5#*B3#*E#-A2#*B#
680 XL0#=XL0#+A#+A4#*B2#*D#-A4#*A5#*B2#*E#+B2#*B4#*E#-B2#*C#
700 XR4#=J#
710 XR3#=I#-J#*A15#-A14#*J#-A13#*J#-A12#*J#
720 XR2#=J#*A15#*A14#-I#*A14#+H#-B14#*J#-A13#*I#+A13#*A15#*J#+A13#*A14#*J#
730 XR2#=XR2#-J#*B13#-A12#*I#+A12#*A15#*J#+A12#*A14#*J#+A12#*A13#*J#
740 XR2#=XR2#-B12#*J#
750 XR1#=A13#*A14#*I#-A13#*A14#*A15#*J#-A13#*H#+A13#*B14#*J#-B13#*I#
760 XR1#=XR1#+A12#*A14#*I#-A12#*A14#*A15#*J#-A12#*H#+A12#*B14#*J#+A12#*A13#*I#
770 XR1#=XR1#-A12#*A13#*A15#*J#-A12#*A13#*A14#*J#+A12#*B13#*J#-B12#*I#
775 XR1#=XR1#+A15#*B12#*J#+A14#*B12#*J#+A15#*B13#*J#+G#
780 XR0#=A12#*A13#*A14#*A15#*J#-A12#*A13#*A14#*I#+A12#*A13#*H#
790 XR0#=XR0#-A12#*A13#*B14#*J#+A12#*B13#*I#-A12#*A15#*B13#*J#-A12#*G#
800 XR0#=XR0#+F#+A14#*B12#*I#-A14#*A15#*B12#*J#+B12#*B14#*J#-B12#*H#
830 PRINT
850 PRINT "INPUT THE VALUE OF X-MID AND XSCAL FOR THE FIRST "
860 PRINT " EQUATION ";
870 INPUT "",XMD1#,XSC1#
875 PRINT
880 PRINT "INPUT THE VALUE OF X-MID AND XSCAL FOR THE SECOND "
890 PRINT " EQUATION ";
900 INPUT "",XMD2#,XSC2#
905 CLS
910 'XXLL#=(XL#-XMD1#)*XSC1#
920 'XXRL#=(XL#-XMD2#)*XSC2#
930 XXLM#=(XM#-XMD1#)*XSC1#
940 XXRM#=(XM#-XMD2#)*XSC2#
950 'XXLR#=(XR#-XMD1#)*XSC1#
960 'XXRR#=(XR#-XMD2#)*XSC2#
970 VAML#= XL4#*XXLM#^4 + XL3#*XXLM#^3 + XL2#*XXLM#^2 + XL1#*XXLM# +XL0#
980 VAMR#= XR4#*XXRM#^4 + XR3#*XXRM#^3 + XR2#*XXRM#^2 + XR1#*XXRM# +XR0#
990 IF VAMR#-VAML#<0 GOTO 1020
991 ' S#=XR4#-XL4#
992 ' T#=XR3#-XL3#
993 ' U#=XR2#-XL2#
994 ' V#=XR1#-XL1#
995 ' W#=XR0#-XL0#
1000 XL#= XM#
1005 XM#=(XL#+XR#)/2
1010 GOTO 1040
1020 XR#= XM#
1030 XM#=(XL#+XR#)/2
1040 IF (XR#-XL#)<1E-14 GOTO 1192
1050 IF ABS(VAML#-VAMR#)<1E-14 GOTO 1192
1160 GOTO 910
1192 PRINT "THE SOLUTION TO THE FREQUENCY THAT CORRESPONDS TO THE INTERSECTION"
1193 PRINT "OF THE TWO QUARTIC EQUATIONS IS ";XM#
1194 PRINT
1195 V1#=XR4#*XXRM#^4+XR3#*XXRM#^3+XR2#*XXRM#^2+XR1#*XXRM#+XR0#
1196 V2#=XL4#*XXLM#^4+XL3#*XXLM#^3+XL2#*XXLM#^2+XL1#*XXLM#+XL0#
1197 PRINT "THE VALUE OF THE NATURAL LOG OF THE AMPLITUDE FROM EQUATION 1 & 2"
```

```
1198 PRINT "RESPECTIVELY ARE ";V1#,V2#
1199 PRINT
1200 FE1#=.707*EXP(V2#)
1202 FE2#= .707*EXP(V1#)
1205 LN2#=LOG(FE2#)
1210 LN#=LOG(FE1#)
1220 XL01#=XL0#-LN#
1225 XR01#=XR0#-LN2#
1230 XR#=XM#
1240 XL#=FL#
1250 XM1#=(XR#+XL#)/2
1260 XXLL#=(XL#-XMD1#)*XSC1#
1270 XXLM#=(XM1#-XMD1#)*XSC1#
1280 XXRM#=(XR#-XMD1#)*XSC1#
1300 VALM#=XL4#*XXLM#^4 + XL3#*XXLM#^3 + XL2#*XXLM#^2 + XL1#*XXLM# + XL01#
1310 IF ABS(VALM#)<1E-14 GOTO 1492
1320 IF (XR#-XL#)<1E-14 GOTO 1492
1330 IF ABS(VALM#)=VALM# GOTO 1370
1340 XL#=XM1#
1350 XM1#=(XL#+XR#)/2
1360 GOTO 1260
1370 XR#=XM1#
1380 XM1#=(XR#+XL#)/2
1390 GOTO 1260
1492 PRINT "THE FREQUENCY CORRESPONDING TO .707 OF THE PEAK AMPLITUDE "
1493 PRINT "OF THE LEFT SIDE OF THE PEAK IS ";XM1#
1494 PRINT
1495 XL#=XM#
1496 XR#=FR#
1500 XM2#=(XM#+XR#)/2
1510 XXRM#=(XM2#-XMD2#)*XSC2#
1520 VARM#=XR4#*XXRM#^4 + XR3#*XXRM#^3 + XR2#*XXRM#^2 + XR1#*XXRM# + XR01#
1530 IF ABS(VARM#)<1E-14 GOTO 1692
1540 IF (XR#-XL#)<1E-14 GOTO 1692
1550 IF ABS(VARM#)=VARM# GOTO 1590
1560 XR#=XM2#
1570 XM2#=(XL#+XR#)/2
1580 GOTO 1510
1590 XL#=XM2#
1600 XM2#=(XL#+XR#)/2
1610 GOTO 1510
1692 PRINT "THE FREQUENCY CORRESPONDING TO .707 OF THE PEAK AMPLITUDE "
1693 PRINT "OF THE RIGHT SIDE OF THE PEAK IS ";XM2#
1694 PRINT
1695 LF# = (XM2#-XM1#)/XM#
1696 PRINT " THE LOSS FACTOR FOR THIS DATA IS ";LF#
1700 OPEN A$ FOR OUTPUT AS #2
1710 PRINT #2,A#,B#,C#,D#,E#
1720 PRINT #2,A1#,A2#,A3#,A4#,A5#
1730 PRINT #2,B1#,B2#,B3#,B4#,B5#
1740 PRINT #2,F#,G#,H#,I#,J#
1750 PRINT #2,A11#,A12#,A13#,A14#,A15#
1760 PRINT #2,B11#,B12#,B13#,B14#,B15#
1770 PRINT #2,""
1780 PRINT #2,"THE LOSS FACTOR FOR THIS DATA IS ";LF#
1790 PRINT #2,"THE VALUE OF THE PEAK HEIGHT IS ";V1#
1800 PRINT #2,"AT A FREQUENCY OF ";XM#
1810 PRINT #2,"FREQUENCIES AT .707 OF PEAK HEIGHT ARE ";XM1#;XM2#
1820 PRINT #2,"THE FILE NAME FOR THIS DATA IS ";A$
1830 CLOSE #2
```

```
1850 INPUT "WOULD YOU LIKE TO DO ANOTHER CURVE FIT ";A$
1860 IF A$="Y" OR A$="y" THEN GOTO 1880
1870 GOTO 1900
1880 CLS
1890 GOTO 80
1900 END
```

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